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**FINAL REPORT**  
**SPECIAL CONTRACT(SPC-92-4021)**

**Title:** Transitioning to potential application the outcome of investigations undertaken with the support of SDI/AFOSR in its OGGAM collaborative US-UK research programme.

**Name:** G. E. Gallagher-Daggitt

**Organisation:** Gallagher-Daggitt Associates

**Address:** HAYFIELD HOUSE  
9 Tullis Close  
Sutton Courtenay  
Oxfordshire OX14 4BD  
Phone: (0235) 848288

**Submitted to:** Lt.Col. Chester J. Dymek Jr.PhD  
Deputy Commander and Chief Chemistry,  
EOARD  
223/231 Old Marylebone Road  
London NW1 5TH

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**ABSTRACT**

Certain areas of collaborative US-UK research funded by the Innovative Science and Technology office of SDIO via AFOSR had reached a stage of advancement where it was considered that these were no longer appropriate to 6.1 research funding. In particular, research which was carried out at the universities of Manchester and Loughborough in collaboration with Gel-Tech Inc., Fla. and the Advanced Materials Research Centre(AMRC) of the University of Florida, was concerned with novel applications for sol-gel glasses in the fields of lasers, optical devices and holographic imaging. The aim of contract F61708-92-5 was to transition this work into one or more of the defence research laboratories in the USA. This final report is concerned with the outcome of these attempts.

## SOL-GEL SILICA COMPONENT APPLICATIONS

### INTRODUCTION

Sol-gel chemical processing of silica provides a new approach to the preparation of optical components and promises several advantages relative to traditional methods of manufacturing such components. Many of the hand operations associated with traditional methods are eliminated and functionality can be imparted, not only by near net shape casting, but also by modifiers that can be added either as constituents at the sol chemical precursor-preparation stage or, by impregnation of the porous matrix of the sol-gel glass in a post processing stage. Other advantages of GELSIL over other commercial silicas is its higher index of refraction( $n$ ) and its lower dispersion( $dn/d\lambda$ ). The index of refraction can be varied according to the thermal processing schedule, it is therefore possible to produce a wide range of optical waveguides in a process which lends itself to an integrated optics technology. Moreover active optical components can be made with a higher degree of control than is possible when traditional glasses are chemically doped. The doping process associated with sol-gel enables a highly homogeneous distribution of additives in a dense silica matrix. This opens up the possibility of constructing optical components with functionalities such as filtering, glass lasers, holographic image storage and non-linear optical.

The feasibility of interesting optical devices has been demonstrated. However there is still much work that needs to be carried out, such as investigating the interactions between dopants and the sol gel matrix in order to ensure long term photostability. Such investigations would be best carried out by the universities concerned in collaboration with a defence research laboratory. Other work needs to be done on the sol-gel at the process level in order to guarantee the accuracy of sol-gel rods which serve as host materials for the impregnant lasing materials in laser applications.

### MANCHESTER UNIVERSITY ACCOMPLISHMENT/APPLICATIONS SUMMARY

**NEW SOLID STATE LASERS** ; an investigation into undoped and doped sol-gel glasses has been carried out for laser, optical and optoelectronic applications. Methods for the doping and characterisation of sol-gel glasses have been developed. Lasers based on gel-silica glass doped with organic molecules and operating from near UV to the near IR have been produced. The basic properties of the composite materials which have been measured include dopant distribution, optical quality and photostability. Fundamental parameters and mechanisms for the doped systems: fluorescence lifetime, quantum efficiency and uniformity have been investigated.

The wavelength range of doped gel-silica lasers has been extended significantly from 360nm using phenyl-biphenyl-oxadiazole(PBD) die to 630nm with Sulforhodamine 640. Tunable lasers based on organic dopants, in either rod or slab form of up to 12cm in size, will generate output energies of about 1J. These achievements enable a wide range of inorganic dopants, such as Nd, as well as the organic dopants mentioned, to be considered for new laser systems, particularly in the near UV, visible and near IR owing to the good optical transmission quality of the silica sol-gel glass. Flashlamp excitation is feasible and long duration excitation, pulsed in the microsecond region, have been demonstrated.

A valuable laser for laser radar(LIDAR) is the Ho laser operating at 2 microns in the eyesafe region, with energy output in the Joule region. Another novel possibility is excitation by diode pumped Nd:YAG at kHz which could give quasi-CW(50ns pulses at 10-10,000Hz) more easily than conventional CW argon ion pumping. With multi-flashlamp excitation in miniature laser cavities a high repetition rate, extremely compact laser is a possibility.

**OPTICAL WAVEGUIDES** by writing controlled densification so as to create an increase in the refractive index of the sol-gel glass, either in bulk or in thin films, has been demonstrated.

This enables the writing of waveguides which opens up the way to many applications in optoelectronics. A novel method of densifying photosensitised sol-gel glass so as to give high spatial resolution enabling micron size waveguides to be written has also been demonstrated. The potential applications of this technique are the writing of waveguides for interconnects in photonics applications, the writing of micro-optical elements in the form of micro-lens arrays and Fresnel lenses for optical signal processing and large area densification which would be applicable to large area optical substrates and light weight mirrors.

#### **POTENTIAL APPLICATIONS OF SOL-GEL BASED OPTICAL DEVICES**

(a) **DENSE BULK SILICA:** net shape optics from precise moulding (tolerance 25 microns), lenses, aspheric, Fresnel lens, arrays, mirrors and graded index optics.

(b) **OPTOELECTRONICS:** novel high performance materials, passive and active channel waveguides, modulators, switches, interconnects, multiplexers and couplers. Also lasers, nonlinear organics/polymers in gel, semiconductor quantum dots, magneto-optical memories and optical fibres.

(c) **HOLOGRAPHIC ELEMENTS:** HOE optics, CD-ROM optical disc displays.

(d) **FILMS AND COATINGS:** optical sensors, photochromic, antireflection, electrochromic, thermochromic smart windows. Other functionalities: piezoelectric, ferroelectric and electroconductive, also protective coatings (scratch, humidity and optical resistant).

(e) **DEVICES:** scintillator detectors, fluorescent converters, solar concentrators. Optical filters, Faraday effect glasses.

(f) **PASSIVE WAVEGUIDES:** optical transmission, thick films.

(g) **NONLINEAR ACTIVE WAVEGUIDES:** frequency conversion and electro-optic modulation or all optical modulator (Mach-Zender Interferometer), optical switching (nonlinear directional coupler, distributed feedback grating waveguide).

#### **LOUGHBOROUGH UNIVERSITY ACCOMPLISHMENT APPLICATIONS SUMMARY**

**EDGE ILLUMINATED HOLOGRAMS:** such displays are entirely novel and could find application in aircraft cockpits or automobiles. They are made possible by the application of two new materials: sol-gel silica from Gel-Tech Inc. and a photopolymer made by Du Pont, Wilmington, Delaware, in a unique way where the reference beam enters at grazing incidence. The sol-gel serves as host to the photopolymer. This method enables the creation of holograms which are only reconstructed by illumination from the edge. The images are therefore totally secure in terms of interrogation from frontal or rear illumination.

**NOVEL ELECTROLUMINESCENT DEVICE:** anthracene exhibits electroluminescence, but is fragile in its unprotected form. In order to overcome this limitation it is impregnated in a gel-silica matrix having pores of 40 angstrom size, the size needed for the excitonic energy transfer mechanism and so a uniform fluorescent solid which emits in the blue wavelength. It is intended to use this material for embossing complex laser gratings (pitch 100nm) using an embossing tool illuminated by silica anthracene complex. The intention is to cure the monomer by the use of a uniformly illuminated tool that is preprofiled using e-beam lithography. This is used to press a pattern into a monomer layer and to cure the monomer while in contact. The technique has great potential for the future of the communications industry where the production of gratings for distributed lasers are a major bottleneck in manufacture.

## SUMMARY AND CONCLUSIONS

A list of the optoelectronic investigators approached with a view to engineering their collaboration with Manchester and Loughborough thereby ensuring technology transfer, is given at Annex 1. This list is restricted to those working in the DoD research sector, in the belief that it is they who serve as the natural route for channelling novel materials and technology into emerging defence systems.

Some of those listed, notably Alvin Goodman of ONR, J. Johnson of ARDC and J. Zavada of ARO are concentrating their work in on devices based on inorganic semiconductor materials, thus the Manchester/Loughborough work is not complementary to their current programme. Another, Joy Arthur of White Sands, has moved away from research in this area and has therefore now lost interest in it. D. Hanson of RADC, Griffis is concerned more with embryo systems based on advanced, but proven technologies. Alan Craig of AFOSR is sponsoring a small amount of work in the field of organic optoelectronic materials. This is being carried out by Stegeman at Arizona and by Knobel at Oklahoma. However the subject does not easily fit into the main theme of his research which is concerned with Electro-Optical Computer Networking. Lt. Col. Germet in applications at AFOSR has been shown a white paper but has not as yet responded. Finally, Ward Trussel of NVL, D. R. Payne of RADC, Hanscom and Vern Smiley/Guy Beaghtler of NOSC remain interested but any development will depend on their priorities and the level of their finances in 1993.

Manchester are already receiving a low level of support from DARPA for work relating to NLO applications of Sol Gel glasses. DARPA were therefore not approached. Manchester are also receiving some Science and Engineering Council SERC (NSF equivalent) aid to finance a research student who is maintaining a low level presence in their organic laser research. This work is being carried out in an informal collaboration with Prof. Bruce Dunn of UCLA, Prof. Wilson of the University of Florida and with Prof. f. Reisfeldt in Israel.

Loughborough have neither SERC nor any other form of US or UK Government funding, they manage with some low-level assistance from DuPont, USA, related to exploiting an experimental DuPont photo imaging-polymer for holographic image storage. They also have some support from Sharp of Japan on 3-D TV research, and are seeking venture capital in the USA to exploit a binocular TV/video invention that is worn like a pair of light-weight binoculars.

Insofar as large Defence related companies (Lockheed, Hughes, Martin Marietta, Boeing, Macdonald Douglas etc) are concerned, these were not approached. Past experience in attempting to transition innovative technology to this sector was not such as to generate optimism. In fact the Vice President for research of a major aerospace company, who is also head of their corporate research laboratory in the USA, informed the writer that his laboratory had never succeeded in transferring their emerging technology directly into any of their operating companies, it had always been transferred via a small independent company which had been awarded a licence.

Small and medium sized industrial firms were not solicited in this attempted technology transfer. This is recognised as an obvious omission in the trawl that was made of potential interests.

G.Gallagher-Daggitt

**GALLAGHER-DAGGITT ASSOCIATES**

25 January 1993

See attached:

Annex 1: DoD Research Agencies Solicited.

Annex 2: Summary of Contract Related Travel.

## ANNEX 1.

DoD AGENCIES: SOL GEL-NLO-LASERS

<u>AGENCY</u>	<u>SCIENTIST</u>	<u>STATUS/OUTCOME</u>
AFOSR	Dr. Alan Craig, AFOSR/NE, Bolling AFB, Washington DC 20332-6448 Tel. 202-767-4931	4-11-93 Subject does not lie within field of interest, but will pass on to Howard Schlossberg in Physics & Electronics and Lt.Col Germat in applications. Doing a little matls. work with Stegeman in Arizona and Knobel/Senoni, Oklahoma. Discussed and WP sent. <u>Electro-optical Computer Networking</u>
NOSC	Dr. Keith Bromley, NOSC Code 2601-T, 271 Catalina Blvd., San Diego CA92152- 5000 Tel.619-553-2535	19-10-93 Subject not in immediate field of interest. Pass on to Dr. Vern Smiley (619- 553-6128) and Dr. Guy Beaghtler. NRAD 804 . Discussed and WP sent. <u>Parallel Processing</u>
ARDC	Dr. John Johnson, ARDC CSSD-H-V, PO Box 1500, Huntsville, AL 35807- 3801. Tel.205-895-4819	10-7-92 Subject of interest, but concentrating on optical diode and similar SS devices. <u>Satellite Laser Communications</u>
ONR	Dr. Alvin Goodman, ONR 800N Quincy Street, Arlington, VA 2217- 5000 Tel.703-696-4218	15-7-92 Met to discuss. Just come in from industry, inherited a portfolio from predecessor which is based on SS inorganic materials. No place for sol-gels. Promised to explore ONR interest. No result when checked on 6-10-92. Gave me some leads. <u>Electrical and Optical Materials</u>
ARO	Dr. Jim Mink/Dr. John Zavada, ARO, PO Box 1211 Durham, NC 27709 Tel. 919-549-4314/4297 FAX 4310	12-11-92 Not in immediate field of interest Has passed papers on to Dr. B. Guenther, Electronics Division. <u>Electronics/Optics</u>
NVL	Dr Ward Trussel, Night Vision Lab., Ft. Belvoir VA. FAX 703-704-1752	16-11-92 Sent WP. <u>Lasers/NLO</u>
WHITE SANDS	Dr. Joy Arthur, White Sands Missile Range, NM FAX 703-704-1752	16-11-92 Sent WP.
RADC Hans.	Dr. D.R. Payne, Rome Lab. RL/ERO Hanscom AFB MA 01731 Tel. 617-377- 5129/2234	4-1-92 Interested. Sent WP <u>Electro optic Device Technology</u>
RADC	Dr. Dr.D.W.Hanson, RADC, Griff. Griffis AFB, Syracuse, NY 13441 Tel.315-330-4365	18-11-92 Contact not yet made. <u>Photonics Directorate</u>



USALC Dr.Guenther Wurthman,  
USALC, ATTN: SLCET-DP  
(CRI), Ft. Monmouth,  
NJ07703-5302 Tel. 315-  
330-5302

16-11-92 Paper sent, awaiting response.  
Electronic Technology and Devices Lab.

**ANNEX 2****CONTRACT RELATED TRAVEL  
CONTRACT SPC-92-4021**

<b><u>DATE</u></b>	<b><u>PERSON VISITED AND PLACE</u></b>	<b><u>TRANSPORT MODE</u></b>
22-04-92	Meeting with Professor L. Hench in London.	Rail and car.
27-04-92	Meeting with Professor T.King in Manchester.	Rail and taxi.
06-07-92	As above	As above
29-04-92	Meeting with Professor N. Phillips, Loughborough.	Rail and taxi.
27-07-92	As above	As above
05-05-92	Meeting with Lt.Col. Chet Dymek, EOARD, London	Rail and taxi
24-08-92	As above	As above
30-06-92	Meeting with M. Worboys, Marconi Research, Chelmsford.	Rail and taxi.
01-07-92	Meeting with Professor Windell, Cambridge University.	Rail and taxi.
10-08-92	Meeting with Professor Ward, Leeds University.	Rail and taxi.
15/16/17 -07-92	Meetings at SDI and ONR, Washington, DC	Air/Rail/Taxi.
18/19/20 -07-92	OGAMM Meeting in San Diego.	Air/Taxi/Rail
27/11/92 04/12/92	Meetings in Washington DC DoD agencies, SDIO etc.	Air/Rail/Taxi